Indian Journal of Pure & Applied Physics
Vol. 45, August 2007, pp. 687-691

Electrical properties of thermally evaporated doped and undoped films of CdSe

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Received 21 August 2006 ; revised 21 May 2007 ; accepted 5 June 2007

Electrical characteristics of Ag-doped and undoped films of CdSe have been reported. The activation energies at lower and elevated temperatures have been found to be 0.22 and 0.6eV, respectively. The Sn/CdSe junction exhibits Schottky barrier characteristics with diode ideality factor deviating from unity. Barrier height obtained from *C-V* plot and *J-V* plot are 0.8 and 0.72eV, respectively. The junction has been endowed with high series resistance.

Keywords: Electrical properties, Activation energy, Schottky barrier, Cadmium selenide

IPC Code: H0L

1 Introduction

Cadmium selenide, a group II-VI compound semiconductor has been considered as an important candidate for opto-electronics and solar cell applications. This compound with direct intrinsic gap (~1.74eV) has been studied extensively for its possible use in device fabrication. Mahawela *et al*[1]. studied transparent thin film CdSe solar cell, Murali *et al*[2]. studied photo-electrochemical solar cell based on CdSe, Klement *et al*[3]. reported diffusion of oxygen in CdSe photosensor, Gogoi and Barua[4] reported breakdown and electrical conduction in CdSe film, Lee *et al*[5] investigated trap density and mobility in CdSe film, Antohe *et al.*[6] investigated the effect of electron irradiation in CdSe film layer, Pethinettam *et al*[7] . reported the effect of thickness and substrate temperature on CdSe films.

Several methods of preparation of CdSe films have been reported in various literatures in recent years. The properties of the films however are largely dependent on preparation technique and environmental state of the deposition chamber. Most frequent techniques used by researchers are in general ; thermal evaporation[6-10], electrodeposition[11], sputtering[12], spray pyrolysis[13], laser ablation[14], solution growth[15], hot wall deposition[16] etc. These films are mostly in undoped state and reported to be *n*-type in nature. However, a few doped films[17] and *p*-type conductivity[18] in CdSe have also been reported. A thorough study of various aspects of the film are important for application of CdSe in device fabrication. In this paper, both doped and undoped films of CdSe and junctions with metal prepared by thermal evaporation method have been reported. The films were doped with Ag metal and counter electrodes were vacuum deposited Sn metal. Base electrodes were vacuum deposited either Ag or Al metal.

2 Experimental Details

The films of cadmium selenide have been prepared from 99.99% pure CdSe powder (Aldrich Chem Co, USA) in a vacuum evaporation unit (VICO-12) at a residual air pressure of 10^{-5} torr. For preparing Ag-doped film, CdSe was vacuum evaporated along with Ag powder (99.99% purity) at the ratio of 95:5. Chemically cleaned glass substrates were used for deposition of the films provided with appropriate masks. Substrate temperature was kept within 215° to 250°C during deposition of the films. The films were baked in vacuum at 100°C for 1 h.

Electrical characteristics of the film were measured by using two co-planer electrodes separated by a gap of 2 mm. These were vacuum evaporated at the two ends of the rectangular CdSe strip. To fabricate metal-CdSe junction, Sn electrode was vacuum deposited onto the previously deposited CdSe film. Both disc and rectangular type electrodes were used as counter electrodes. Base electrode used was vacuum deposited Al on glass substrate. For studying Sn/CdSe junction, we only used Ag-doped samples.

All the measurements were carried out in a specially designed vacuum chamber fitted with a tem-

perature controller (Philips-LD30). The pressure of the chamber was kept at 10^{-3} torr during measurement. The capacitance-voltage characteristics and current-voltage characteristics were measured by L-C-R bridge (Aplab) and X-Y recorder (Omniscribe) respectively. The details of the measurement have been reported in our earlier paper[19].

3 Results and Discussion

Fig. 1 shows the variation of conductivity with temperature for both doped and undoped samples. It has been observed that at lower temperature both type of samples exhibit activation energy around 0.22eV. At slightly higher temperatures, undoped film shows another activation energy around 0.65eV. The activation energy at lower temperatures is due to the shallow traps available below the conduction band[20]. The activation energy at higher temperature for undoped film may be attributed to the presence of selenium vacancies as was reported by earlier researchers[16,21]. In case of Ag-doped films, films are mostly disordered with slight decrease of band gap. This is due to doping effect and change of stoichiometry. Similar observation was also reported by earlier researchers in Ag-doped films[9]. Both types of films are unstable after preparation and exhibit aging effect (Fig. 2). The resistivity shows a rapid change during initial stage and become stable at about 10 days after preparation. This decrease of σ may be partly due to aging and partly due to exposure of the film to atmosphere. Such type of effect has been reported by previous researchers on CdSe films[22]. The films show ohmic contact to Ag and Al electrodes up to about 3V at room temperature as tested for sandwich structure. Fig. 3 shows current-voltage (J-V)characteristics of Sn-CdSe-Al structure. The current density-voltage characteristics of an ideal Schottky junction can be represented by[23]

$$J = J_O \exp(qV/nkT)\,[1 - \exp(-qV/kT)]$$

where J_O is the reverse saturation current density and n is the diode ideality factor.

The junction shows more or less ohmic nature at very low voltage below 0.5V. However, at higher voltage the current indicates $I \alpha V^2$ relation as observed from the plot of log I versus log V (not shown here) curve. The reverse current does not saturate and shows voltage dependent of barrier height.

Fig. 4 shows the linear dependence of C^{-2}-V plot indicating uniform charge distribution of space charge region. The carrier concentration N_d can be obtained from the expression[24]

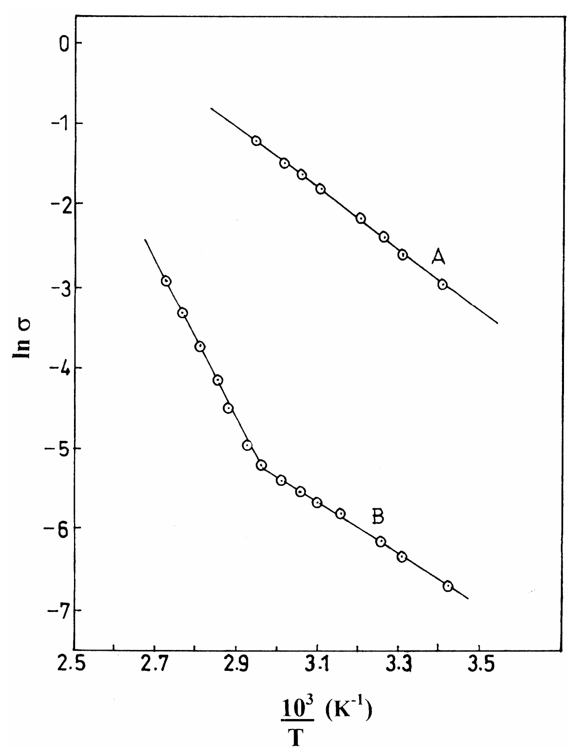

Fig. 1 — Variation of conductivity (σ) with temperature (T) for Ag-doped (A) and undoped (B) films

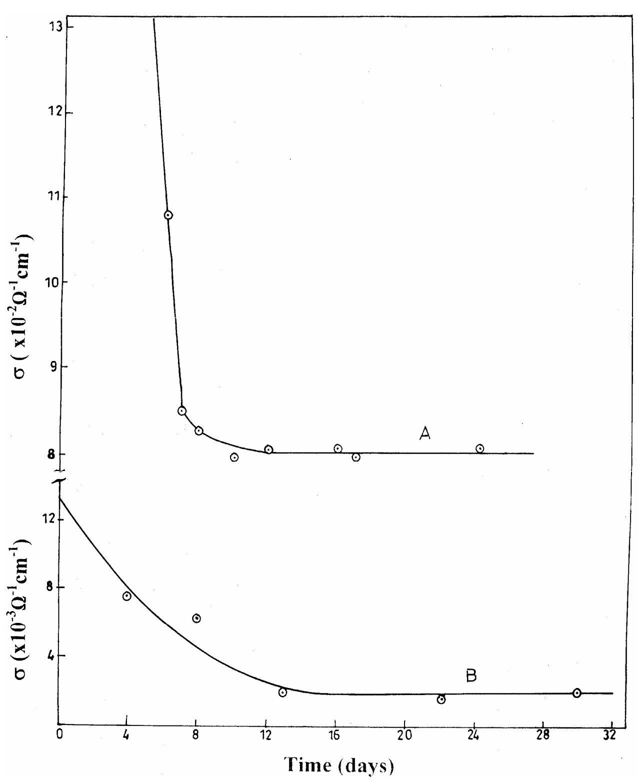

Fig. 2 — Change of resistivity with time for the films of Fig. 1

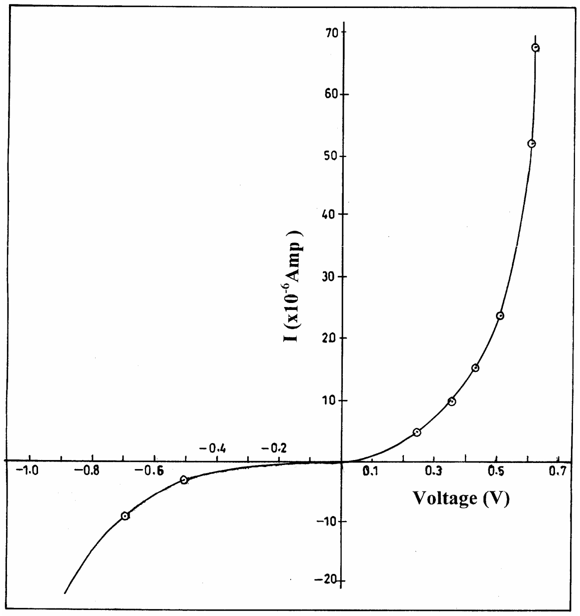

Fig. 3 — Current-voltage characteristics of Sn-CdSe-Al film at room temperature

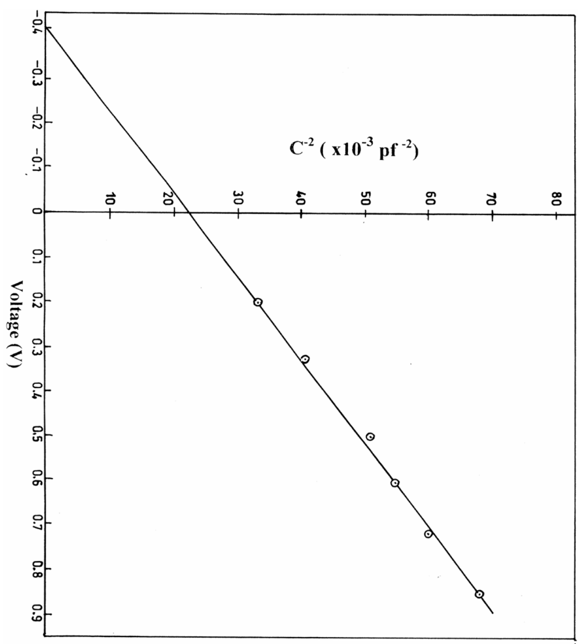

Fig. 4 — Capacitance-voltage plot of Sn-CdSe-Ag junction at room temperature

$$N_d = 2/q\in_s\left[-1/\frac{d}{dv}\left(1/c^2\right)\right] \qquad \ldots (1)$$

where $\in_s$ is the permittivity of the semiconductor.

The potential between the Fermi level and conduction band V_n may be obtained from the equation[23] :

$$V_n = kT/q \ln N_c/N_d \qquad \ldots (2)$$

where N_c is the density of state in the conduction band and can be evaluated from the equation :

$$N_c = 2\,(2\,\pi\, m_e kT/\, h^2) \qquad \ldots (3)$$

where m_e is the effective mass of electron. For CdSe, m_e= 0.13 m_o, where m_o is the free electron mass. The value of N_c calculated from Eq (3) is found to be 1.18×10^{24} cm^{-3} at room temperature. The value of N_d and built in potential V_b evaluated from C^{-2}-V plot are 3×10^{14}cm^{-3} and 0.4V, respectively. The barrier height Φ_n of the junction was obtained from the equation ; $\Phi_n = V_b+V_n$. This value evaluated to be about 0.8eV. The junction shows high series resistance as evident from Fig. 5. The plot of ln I versus V shows a series resistance (R_S) of the device in the order of kΩ.

Fig. 6 shows the plot of In $[J/(1\text{-}e^{-qv/kT})]$ verses V at various temperatures below 70°C. The saturation current density J_O obtained from this plot shows a variation from 1.2×10^{-7}A/Sq.cm to 4.12×10^{-6}A/Sq.cm in the temperature range 25-60°C. The Rechardson's constant A^* evaluated from the plot of ln (J_O/T^2) versus T^{-1} (Fig. 7) is around 40A/cm^{-2}K^{-2}. The diode ideality factor (n) for this junction is greater than unity.

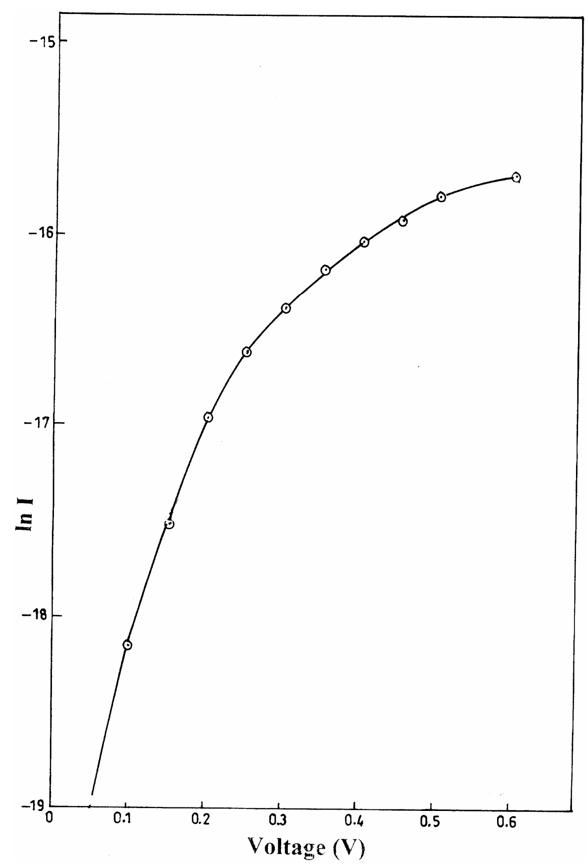

Fig. 5 — ln I versus V plot for Sn-CdSe-Ag junction

Table 1 — Values of some electrical parameters of Sn-(n) CdSe-Al junction at 300 K

Doping Conc (N_d) (cm^{-3})	Series resistance (R_s) (kΩ)	Diode ideality factor (n)	Saturation current density (J_o) (A/cm^2)	Richardson's constant (A^*) $A/cm^{-2}K^{-2}$	Barrier height (eV)	
					From C^{-2}-V plot (eV)	From C^{-2}-V plot (eV)
3×10^{14}	2.2	2.1	1.8×10^{-7}	40	0.8	0.72

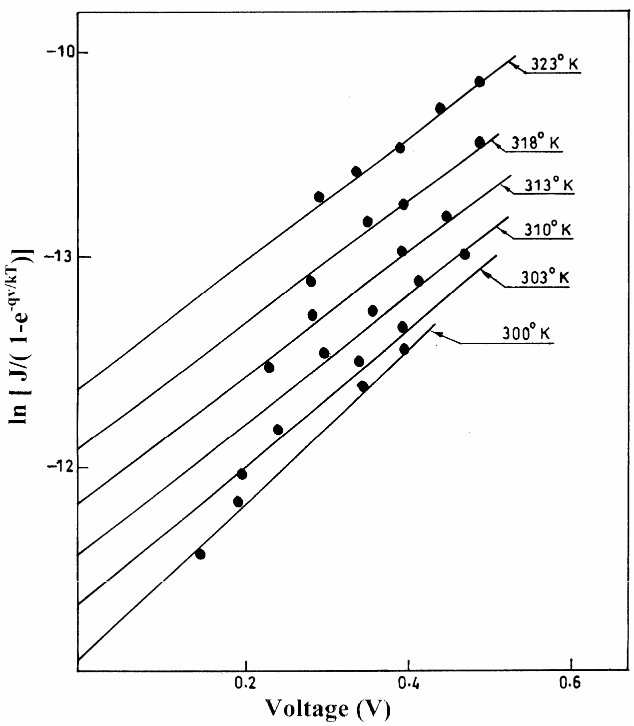

Fig. 6 — ln [1-$e^{-qv/kT}$] versus V plot of Sn-CdSe-Al junction at different temperature

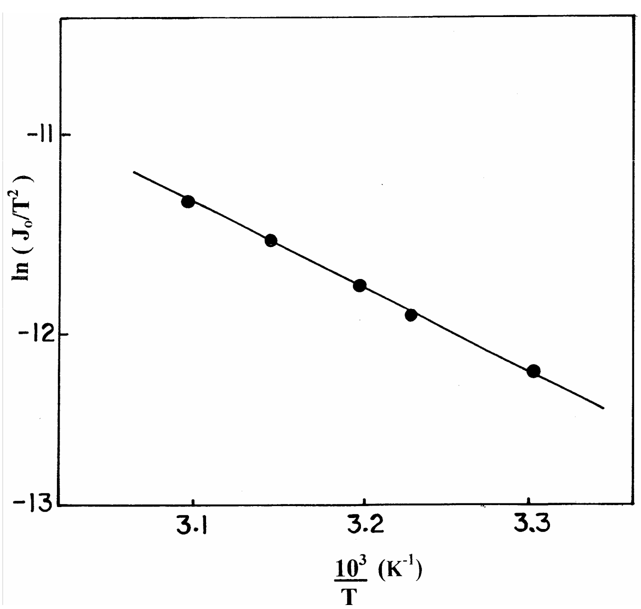

Fig. 7 — ln (J_o/T^2) versus T^{-1} plot of the junction in Fig. 6

Some physical parameters of the junction at room temperature have been shown in Table 1.

Thus, it has been found that Sn forms a Schottky barrier with Ag-doped CdSe film. The deviation of diode ideality factor from unity is, however, caused by a few factors associated with the junction. The junction is affected by high series resistance at the neutral region of the semiconductor. This series resistance causes the actual voltage across the junction to be less than the applied voltage and the current[25] is proportional to $\exp[q(V\text{-}IR_S)/kT\text{-}1]$. Since the doping concentration is moderate, the current transport can be attributed to thermionic emission process. The reverse current does not saturate and shows the tunneling probability due to lowering of potential barrier on the application of bias[25]. Another factor responsible in this case is recombination component of electron and hole in the depletion region, which is prominent in this type of junction. However, this junction can be best represented by the Schottky barrier with a very thin interfacial layer[26]. This layer has been developed due to the exposure of the film to atmosphere before deposition of counter electrode in a separate chamber[22].

While calculating barrier height from the C-V plot, flat band structure has been considered and for J-V curve, image force lowering of barrier height has not been taken into account .

4 Conclusion

Ag-doped and undoped films of CdSe films indicate different resistivity variation with temperature. Ag-doped films are mostly disordered. A study on Sn/CdSe/Al structure shows that a Schottky barrier has been formed in the junction with a deviation of diode ideality factor from unity. The few factors have found responsible for this deviation are series resistance, recombination component and thin interfacial layer.

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